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Dilute Spent Kraft Liquor Filtration through Wood Chips

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U.S. DEPARTMENT OF THE INTERIOR ● FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

DILUTE SPENT KRAFT LIQUOR FILTRATION THROUGH WOOD CHIPS

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

DEPARTMENT OF THE INTERIOR

By

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FWPCA Review Notice

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration.

ABSTRACT

The principal objective of this project was to determine if contact between effluent from a Kraft pulp mill and pine chips would reduce the water pollution characteristics of the waste liquor.

The experimental work was divided into two phases: 1) a small scale laboratory investigation of contacting dilute waste liquor with chips; 2) a pilot-scale investigation of filtering waste liquor through a column and a pile of chips.

It was found that contact of alkaline waste liquor, or even distilled water, with pine chips extracted organic matter from the chips which had a considerable BOD_5. This extract corresponded to a pollution load of about 3-11 lbs. BOD_5 per ton of dry wood. Alkalinity, pH, and intensity of color of the waste liquor were somewhat reduced by the contact. These reductions are, however, too small to have any practical application in effluent treatment. It can, in general, be concluded that contact of alkaline waste liquor, or water, with wood chips extracts soluble organics and adds pollutional materials to the effluent stream.

This report was submitted in fulfillment of Grant No. 115-01-68 between the Federal Water Pollution Control Administration and the Department of Wood and Paper Science, School of Forest Resources, North Carolina State University at Raleigh, North Carolina.

Key Words: Water pollution, waste water, BOD-extraction, Kraft pulp mill, wood chips.

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Dilute Spent Kraft Liquor Filtration

Through Wood Chips

I. CONCLUSION

Contact between pine chips and dilute alkaline effluent from a Kraft pulp mill extracted a considerable amount of biochemical oxygen demanding matter from the chips. The pH, electrical conductivity, as well as the alkalinity of the waste liquor were somewhat reduced by contact with the chips. The intensity of color of the waste liquor diminished. It is believed that the change in color is caused mainly by the reduction in pH. The pine chips acted as a good filter-media for the waste liquor. Fibers present in the waste liquor were almost quantitatively removed by filtering the liquor through a chip column or chip-pile. However, the fibers retained on the surface of the chip-column, or pile, hindered penetration of the liquor through the chips.

It can, in general, be concluded that contact of waste liquor from a Kraft pulp mill with wood chips would extract enough BOD from the chips to increase the pollution load of the effluent. Even water extracted a considerable amount of BOD from wood chips. This means that liquid drainage from a mill's chip storage area should be considered as a pollutional waste. The change in pH, alkalinity, and the color reduction obtained by contacting waste liquor with wood chips were too small to achieve practical benefits through industrial application of the system.

II. RECOMMENDATION

It is recommended that contact between pulp and paper mill alkaline effluent and wood chips should be avoided and that drainage, resulting from rainfall and other water sources, from a wood chip storage area should be considered a pollutional waste.

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III. INTRODUCTION

The prime objective of this project was to determine if contact between waste liquor from a Kraft pulp mill, that produces unbleached pulps from southern pine, and the wood chips from which the pulp is subsequently made, reduces the water polluting properties of the waste liquor. The suggestion was based in the fact that wood sawdust, or chips, will absorb alkali from water to reduce its pH, and that wood and cellulose are good adsorbents for phenols and tannins. The experimental work was divided into two phases. The first of these was a laboratory investigation to determine changes in the water polluting characteristics of the waste liquor after contact with pine chips. The second phase involved pilot-scale investigations by filtering waste Kraft pulping liquor through pine chips at the plant site of the cooperating company, Albemarle Paper Corporation at Roanoke Rapids, North Carolina.

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IV. EXPERIMENTAL

A. Analytical Procedures

Standard analytical procedures (1) were used for testing the pollution characteristics of the liquors. These were applied in the laboratory and pilot-scale experiments.

pH was measured with a calibrated Beckman pH meter.

Biochemical oxygen demand (BOD_5) was determined according to the method described in the 12th edition of "Standard Methods for the Examination of Water and Waste Water" (1). The seeding used was domestic sewage taken from Raleigh City sewage treatment plant. The dissolved oxygen content was measured with polarographic DO-Analyzer (Weston and Stack, Inc., Model 300) after calibrating the instrument with solutions which had been analyzed according to the Winkler-Method (1).

Total Alkalinity was determined by titration with a standard solution of hydrochloric acid to the carbonic acid equivalent point of pH 4.5, using a Beckman pH-meter.

Electrical conductivity was measured with a calibrated conductivity bridge.

Suspended solids were determined by filtering the liquor through an analytical filter paper (Whatman 40), drying the paper at 103°C for 1 hour, and determining the weight increase.

Total dissolved solids were measured by evaporating a known volume of liquor and weighing the residue after drying it at 103°C to constant weight.

Fixed residue or inorganic solids (ash) were determined by ignition of the evaporated residue at 600°C to constant weight in a muffle furnace.

Moisture content of the chips was found by drying the chips at 103°C to constant weight.

B. Laboratory Experiments

Pine chips were shipped to North Carolina State University, Robertson Laboratory, from the cooperating mill in 55 gallon containers. The chips were placed in plastic bags, and could be stored for several months without any loss in moisture, discoloration

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or any other evidence of degradation. The waste liquor used for the experiments was effluent from the mill's decker-operation, which increases the consistency of the pulp after the low consistency screening operation. In this mill the decker-operation also acts as a final washing stage. It was found that if the waste liquor was kept in closed polyethylene carboys of 5 gallons at 4°C, it could be stored for one to two months without any change in pH or BOD. In the laboratory tests BOD analyses were completed in the test waste liquor, prior to use, after storage periods not exceeding 3 weeks.

Small scale experiments were performed by the mechanical stirring of 100 to 400 grams of wet chips, with a moisture content of 50%, in a three liter beaker containing one liter of waste liquor or water. The tests were made at room temperature (about 25°) and at an elevated temperature of 75°C. In the control experiments no chips were added. Samples of the liquors were taken before and after the treatments. The pollutional characteristics of the samples were determined following filtration of the sampled liquors through filter paper. The experiment was designed to reflect realistic ratios of chips used to waste liquor discharged by a mill. The total waste liquor from a Kraft mill amounts to about 1-2 gallons per pound of dry chips used. In the metric system this would be 60-120 grams of dry chips per liter.

A few experiments were made utilizing a glass column packed with chips. The dimension of the column was 1.5 inches in diameter and about 36 inches in length. The column contained 500 grams of chips with a moisture content of about 50%. This quantity of chips filled the column to a depth of about 30 inches. In each test 1500 ml of the waste liquor was recirculated through the column by a constant volume pump delivering about 500 ml/min. The time of treatment was varied. Liquor samples were taken at different time intervals and analyzed for pH, BOD_5 and suspended solids.

C. Pilot-Scale Experiments at Mill Site

Preliminary experiments were made by filtering effluents from the mill's decker operation through a pine chip column. This was contained in a 55 gallon steel drum. The weight of the chips was 143 lbs. on a wet weight-basis, or about 70 lbs. as oven-dried chips. The effluent was distributed over the top of the chip column by utilizing four paper machine headbox showers which distributed the effluent in a relatively uniform manner. The

four overlapping sprays covered 90% of the area on the top of the column. The flow rate of the effluent was kept at 5 and 3 gal/min. Samples of the effluent, before and after contact with the chips, were taken at different time intervals.

Additional experiments employing a longer column were completed. This column was constructed from 55 gallon drums which were welded together endwise. For one experiment a 10 ft. depth of chips was employed using 575 lbs. of chips. For the second experiment a 6 ft. depth of chips was used employing 340 lbs. of chips. The chip moisture content in both instances approximated 50%. The flow rate of the decker effluent through the column was kept at 1.5 and 2 gal/min. and the liquor was distributed on the top of the column by the four overlapping sprays. A piece of Fourdrinier wire was placed over the top of the column in order to filter out the fibers present in the waste liquor and to prevent plugging of the chip column with fibers. Samples of the liquor were taken before and after contact with the chips at different time intervals and analyzed for pH and BOD_5.

A small experimental chip pile was also constructed which was 12 feet in diameter at the base, 4 feet in diameter at the top and 6 feet high. The pile contained about 4.5 tons of wet pine chips (4400 lbs. of oven-dried chips). The chip pile was placed on a 3 mil. polyethylene sheet and arranged in such a way that all the effluent would drain to one point for sampling of the liquor. Effluent from the mill's decker operation was sprayed on the top of the pile, utilizing the same spray arrangement as for the column experiments. The flow rate was 12 gal/min. The first chip pile constructed was essentially washed away after one week. A second pile equal to the first one was therefore constructed with the base of the pile restrained by a foundation of 1" x 5" boards. Samples of liquor were taken at various time intervals before and after contact with the chips and analyzed for pH and BOD_5.

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V. DISCUSSION OF RESULTS

A. Laboratory Experiments--Treatment of Diluted Spent Kraft Pulping Liquor from the Decker Effluent by Contact with Pine Chips

a) Stirring tests in beaker. Table 1 shows the results of the tests. As the liquor changed on exposure to air, the analysis of a liquor, which was stirred without chip contact for the same period of time as the other test liquors, are included. The most notable changes in the characteristics of the waste liquor by contact with the chips were a decrease in pH, an increase in the content of the volatile matter (organics), and an increase in the biochemical oxygen demand (BOD_5). The amount of inorganic matter was not significantly changed. The electrical conductivity decreased, as expected from the pH-reduction, as a result of the treatment. Contact of liquor with the chips reduced the intensity of the color of the waste liquor but increased its colloidal nature. The change in color could be caused by the change in pH. It is well known that the color of spent Kraft pulping liquor is highly dependent on pH. Although a noticeable color change of the effluent occurred, it was not possible to quantitatively measure the degree of change because the residual color was still too intense to measure accurately.

Analytical data for stirring experiments at 25°C performed on 100 and 200 grams of wet chips, with two new samples of decker effluent, are given in Table 2. The results verified the findings of the former experiments. Organic matter was extracted from the chips by the waste liquor. The BOD-demand of the liquor was thereby considerably increased and the pH and the alkalinity of the liquor was significantly reduced. This was obviously a result of neutralization of the liquor by the extracted wood-acids. The data showed also that the BOD of the waste liquor was reduced by contact with the air. This was probably caused by air-oxidation of sulfides in the waste liquor to their respective oxidation products.

Tables 3 and 4 show the results obtained by contacting pine chips with waste liquor and with distilled water by stirring at about 25°C and at 75°C.

The findings confirmed earlier results and showed also, that even distilled water extracts biochemical oxygen demanding materials from wood chips. At room temperature (about 25°C)

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Table 1. Properties of a waste liquor from a Kraft pulp mill after stirring contact at 25°C with different amounts of pine chips

Chip-Liquor Ratio (g. chips/ liter liquor)	Time of Stirring (hours)	pH	Electrical Conductivity (mho/cm^3)	Volatile Matter (g/liter)	Inorganic Matter (g/liter)	Five day Biochemical Oxygen Demand (ppm)
0	-	8.8				
	1	8.8				
	4	8.7	450	0.36	0.15	225
50	0	8.8				
	1	7.5				
	4	6.9	410	0.56	0.18	315
100	0	8.8				
	1	7.0				
	4	6.6	370	0.99	0.14	330
200	0	8.8				
	1	6.9				
	4	6.5	350	1.14	0.19	310

Table 2. Properties of waste liquors from a Kraft pulp mill after stirring contact at 25°C with different amounts of pine chips

Waste liquor	Chip-Liquor Ratio (g. dry chips/ liter of liquor)	Time of Stirring (hours)	pH	Alkalinity (mg/liter) ($CaCO_3$)	Dissolved solids (g/liter)	Inorganic Matter (g/liter)	Biochemical Oxygen Demand (ppm)	Change in Biochemical Oxygen Demand (ppm)
Sample I	0	4	9.0	456	0.7	0.21	90	---
	50	4	7.9	381	---	0.23	255	+165
	100	4	7.7	374	0.9	0.26	315	+225
Sample II	0	0	10.8	717	1.4	0.39	435	---
	0	4	10.4	700	1.3	----	355	-100
	50	4	9.3	600	1.5	0.36	540	+185
	100	4	8.0	535	1.7	----	750	+395

Table 3. Analytical data for waste Kraft pulping liquor and distilled water after stirring separately with pine chips for 1 hour at 25°C

Type of Liquid	Chip-Liquor Ratio (g.dry chips/ liter)	pH	Dissolved Solids (g/liter)	Inorganic Matter (g/liter)	Biochemical Oxygen Demand (ppm)	Change in Biochemical Oxygen Demand (ppm)	Extracted BOD_5 from the Chips (lbs.BOD/Ton of Dry Chips
Waste liquor	0	9.7	1.2	0.4	250	---	
Waste liquor centrifuged*	0	---	1.1	---	250	---	
Waste liquor	50	7.7	1.6	0.4	410	+160	6.4
Waste liquor centrifuged*	50		1.5	0.4	415	+165	
Water	50	5.4	0.3	0.05	75	+ 75	3.0
Water centrifuged*	50	---	0.2	-0.06	90	+ 90	

*Ultra-centrifuging was performed after the treatments.

Table 4. Analytical data for waste Kraft pulping liquor and distilled water after stirring contact separately with pine chips for 1 hour at 75°C

Type of Liquid	Chip-Liquor Ratio (g.dry chips/ liter)	pH	Dissolved Solids (g/liter)	Inorganic Matter (g/liter)	Biochemical Oxygen Demand (ppm)	Change in Biochemical Oxygen Demand (ppm)	Extracted BOD_5 from the Chips (lbs.BOD/Ton of Dry Chips)
Waste liquor	0	9.5	1.4	0.5	300		
Waste liquor centrifuged*	0	---	1.1	0.4	280		
Waste liquor	50	7.6	1.7	0.5	400	+100	4
Waste liquor centrifuged*	50	---	1.4	0.4	380		
Water	50	6.0	0.5	0.04	105		4
Water centrifuged*	50	---	0.3	0.03	95	+100	

*Ultra-centrifuging was performed after the treatments.

the amount of the extracted BOD_5 was, after 1 hour's treatment, about twice as high for the alkaline waste liquor (pH 9.7) as for distilled water. The amounts of BOD_5 extracted from the chips were, on the basis of 1 ton of dry chips, about 6.4 lbs. and about 3.0 lbs., respectively. A one-hour stirring treatment at 75°C showed no difference in the amount of extracted BOD_5 between water and the alkaline waste-liquor. It amounted to about 4 lbs. of BOD_5 per ton of dry chips. Removal of colloidal matter from the liquors by ultra-centrifugation did not significantly change the BOD_5 of the liquors. Two successive treatments of pine chips with the alkaline waste liquor at room temperature (about 25°C) extracted a total amount of BOD_5 equal to about 11.2 lbs. per ton dry chips. This can be seen from Table 5.

b) Recycling tests through chip column. Results from recycling of waste liquor in a small column of pine chips are given in Table 6. The data showed that this treatment gave generally the same pH reduction as did the stirring experiments. The chip column was a very effective filter as it removed almost all the fiber and the other suspended solids present in the waste liquor. The effect on BOD of filtering the waste liquor through the chip column was less apparent than shown by the stirring experiments. This can be explained by a more extensive air oxidation of the waste liquor during the recirculation treatment.

B. Pilot-Scale Treatment of Diluted Spent Kraft Pulping Liquor Effluent by Contacting It with Pine Chips

The preliminary experiments of passing effluent from a pulp decker operation through a column of chips on the plant site of Albemarle Paper Company in Roanoke Rapids, North Carolina, were inconclusive with respect to changes in pH and BOD of the waste liquor. The reason for this was that the chip column became plugged with fiber rather quickly, and the experiments had to be discontinued after a very short period of time. The pH and BOD changes of the effluent on contact with the chips tend to show, however, the same trends that were observed in the laboratory. The results from the mill experiments are shown in Table 7.

Further mill experiments on filtering effluent through a column of chips, were performed with columns of the same diameter as used in the first test, but with 2.4 times as many chips. In these tests to overcome the problem of fibers clogging the column, the liquor was first filtered. The flow rate of waste-liquor through the column was also reduced. The exact experimental conditions and analytical data for a set of duplicating

Table 5. Analytical data for waste Kraft pulping liquor stirring treatments for 1 hour at 25°C with original pine chips, and with the previously treated chips

Treatment	Chip-Liquor Ratio (g.dry chips/liter)	pH	Dissolved Solids (g/liter)	Inorganic Matter (g/liter)	Biochemical Oxygen Demand (ppm)	Change in Biochemical Oxygen Demand (ppm)	Extracted BOD_5 from the Chips (lbs.BOD/Ton of Dry Chips)
Stirring	0	9.5	0.9	0.3	400	---	
Stirring	50 (original pine chips)	7.7	1.3	0.3	580	+180	7.2
Stirring	50 (Previously stir treated chips)	8.0	1.1	0.3	500	+100	4.0

Table 6. Properties of waste Kraft-pulping liquor resulting from recycling of the liquor through pine chips in an open column (lab experiments)

Temp. (°C)	Chip-Liquor Ratio (g.dry chips/liter)	Time of Liquor Cycle, (min.)	Time of Treatment, (min.)	pH	Suspended Solids (mg/l)	Biochemical Oxygen Demand (ppm)
20	0	0	0	10.3	350	350
	170	3	10	9.5	---	---
	170	3	30	8.8	---	---
	170	3	70	7.6	5	375
20	0	0	0	10.3	---	290
	170	3	30	8.8	---	270
	170	3	180	7.1	---	290
	170	3	330	7.1	---	310
75	0	0	0	9.2	---	260
	170	3	5	8.2	---	---
	170	3	10	7.7	---	---
	170	3	15	7.5	---	---
	170	3	20	7.5	---	205

Table 7. Properties of waste Kraft pulping liquor before and after gravity flow of the liquor through a column of pine chips (preliminary mill pilot-scale experiments)

Temp. (°C)	Flow Rate (Gal/lbs. Dry Chips/Hr.)	Elapsed Time of Effluent Flow, (min)	Total Amount of Liquor Contacted by the Chips (Gal/lb. Dry Chips)	pH Before Contact	pH After Contact	Δ pH	BOD_5 Before Contact (ppm)	BOD_5 After Contact (ppm)	Δ BOD_5 (ppm)
30	4.3	10	0.7	10.0	9.5	0.5	375	320	- 55
	4.3	45	3.2	9.6	9.4	0.2	310	410	+100
30	2.6	5	0.2	9.6	9.0	0.6	330	460	+130
	2.6	45	1.9	9.6	9.3	0.3	395	395	0
	2.6	130	5.5	9.6	9.5	0.1	370	410	+ 40

experiments are given in Appendix Table 1 and the results are demonstrated in Figures 1-4. It can be seen that biochemical oxygen demanding materials were extracted from the chips by the alkaline liquor. The bulk of this material was leached out of the chips when 3-4 gallons of waste liquor, per pound of dry chips, had passed through the column. The BOD-results obtained at the end of the second experiment (Fig. 2) can be explained by channeling of liquor through the column. The reduction of pH of the waste liquor followed in general the BOD changes (Figs. 3 and 4): decreasing with time of effluent flow until the reduction became constant at about 0.2 - 0.3 pH units. This constant reduction in pH was probably due to the absorption of carbon dioxide from the atmosphere.

Table 8 shows the approximate increases in biochemical oxygen demand of the waste liquor by filtering it through the chip column, after different amounts of liquor had passed through. The magnitude of the BOD increase corresponds with the BOD increases found in the laboratory stirring-experiments, when the effect of air-oxidation of the liquor is taken into consideration.

In order to investigate what happens when a stored chip-pile is sprayed with the decker effluent for a long period of time, two small experimental piles were built. The results from these spraying experiments are given in Table 9. The piles acted as a good filter medium for fibers and other suspended matter in the waste liquor. This resulted however, in a partial plugging of the surface of the piles and therefore limited contact of waste liquor with the chips. It can be concluded from the experiment that, after the bulk of soluble organics were extracted from the chips, the changes in BOD_5 were not very clear and were in most cases insignificant. A biological slime did form on the pile surface with time. It is likely that the pile acted partially as a biological trickling filter towards the end of the second experiment. The pH reduction was somewhat higher than would be expected from the results of the previous experiments.

C. Practical Aspects

Interest in spraying of stored chips with water or mill effluent for wood preservation has been growing since it was reported in the literature (2) that spraying of stored round-wood-piles with a Kraft mill effluent prevents wood losses and simultaneously reduces the BOD_5 of the mill effluent 60-65%. Recently published data (3) shows, however, that spraying of chips, which

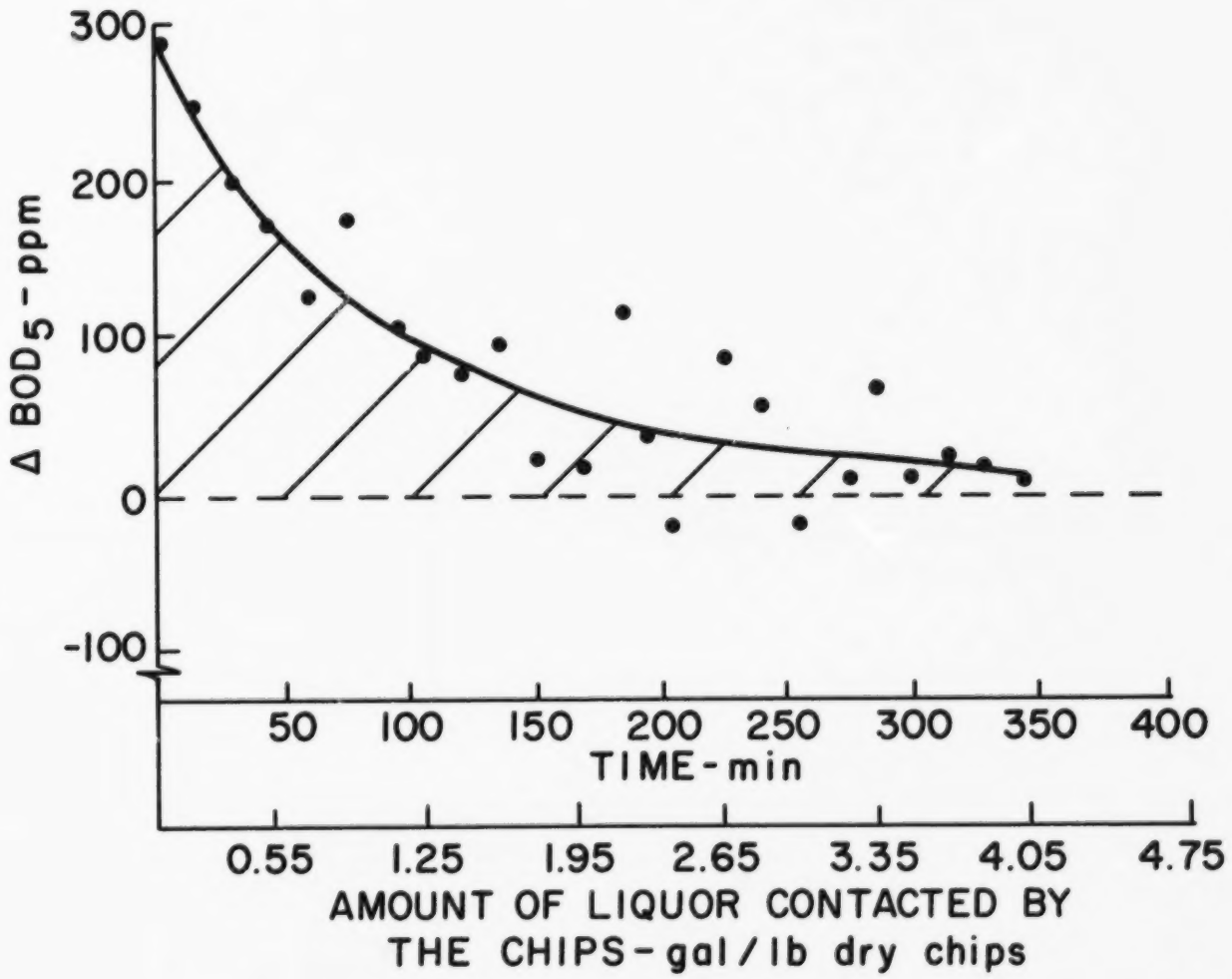

Figure 1. Change in biochemical oxygen demand (BOD) of a waste Kraft pulping liquor of pH 10, resulting from filtering the liquor through a column of pine chips

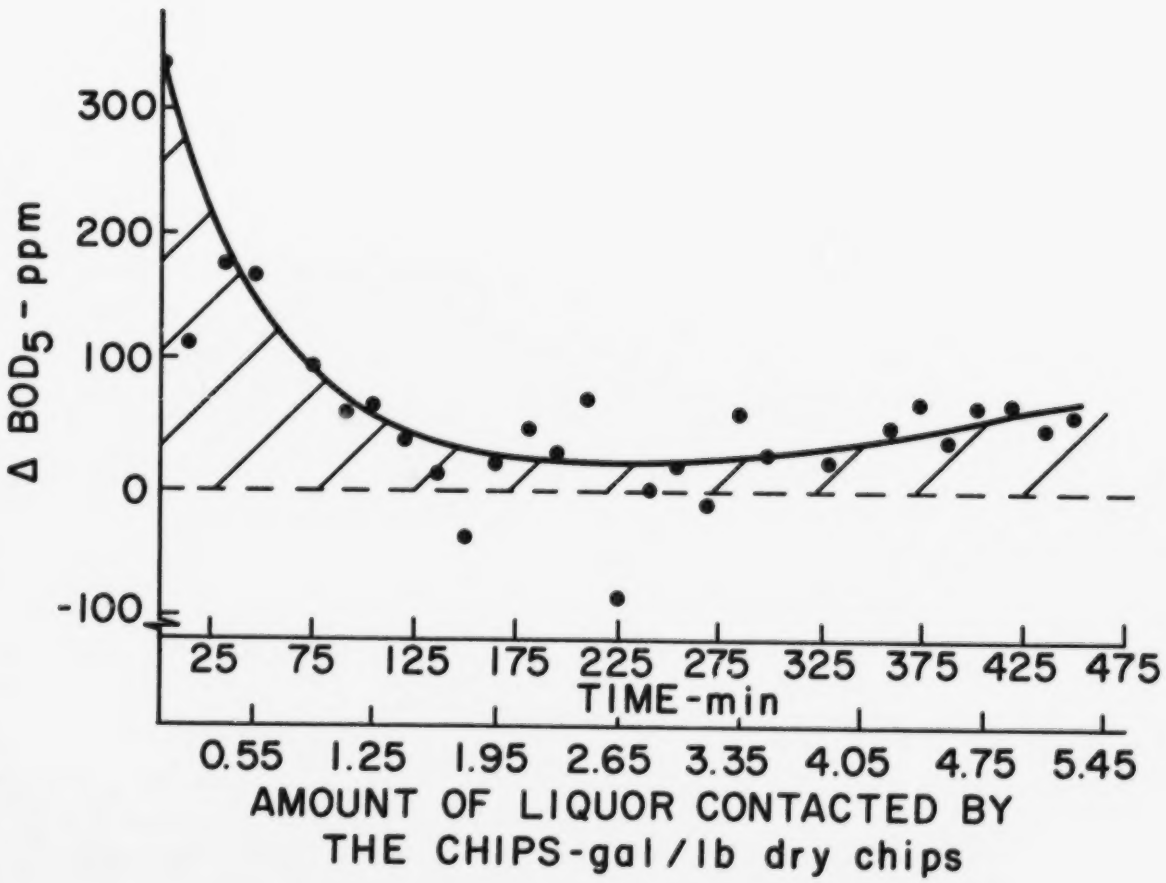

Figure 2. Change in biochemical oxygen demand (BOD) of a waste Kraft pulping liquor of pH 10.5 resulting from filtering the liquor through a column of pine chips

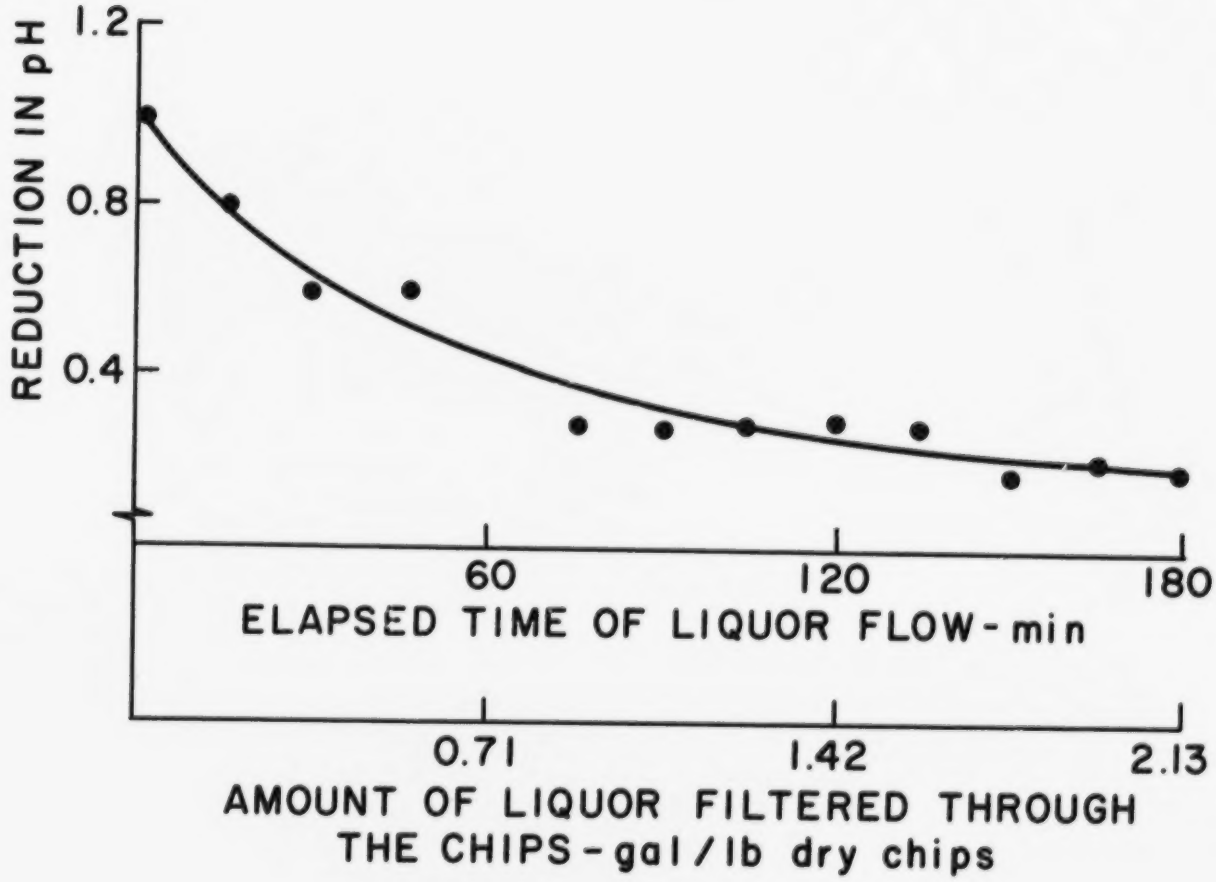

Figure 3. Reduction in pH of a waste Kraft pulping liquor of initial pH 10, resulting from filtering the liquor through a column of pine chips

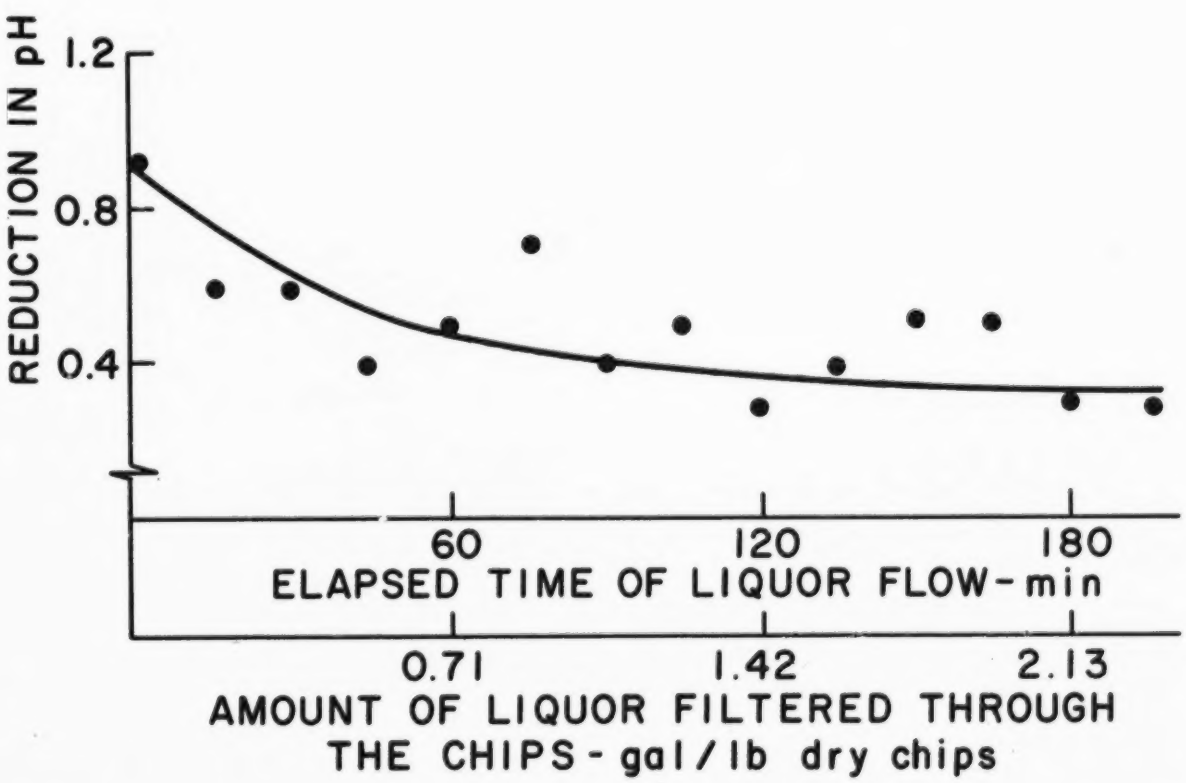

Figure 4. Reduction in pH of a waste Kraft pulping liquor of initial pH 10.5 resulting from filtering the liquor through a column of pine chips

Table 8. Change in biochemical oxygen demand of waste Kraft pulping liquor of pH 10-10.5 resulting from filtering the liquor through a column of the pine chips

Experiment Number	Elapsed Time of Effluent Flow (Hours)	Total Amount of Liquor Filtered Through the Chips (gal/lb. of dry chips)	Increase in BOD_5 of the Total Waste Liquor Passed Through the Chips, (lbs/ton dry chips)
I	1	0.71	2.4
	2	1.42	3.7
	3	2.13	4.5
	4	2.84	5.0
	5	3.55	5.4
	6.0	4.25	5.6
II	1	0.71	2.0
	2	1.42	2.8
	3	2.13	3.2
	4	2.84	3.5
	5	3.55	3.8
	6	4.25	4.20
	7	4.93	4.80
	8	5.65	5.50

Table 9. Changes in properties of waste Kraft pulping liquor by contacting the liquor with pine chips through spraying the liquor over a small chip pile (pilot-scale experiments)

Temp. (°C)	Fow Rate (Gal/lb. Dry Chips/Hr)	Elapsed Time of Effluent Flow (hrs)	Total Amount of Liquor Contacted by the Chips (gal/lb. dry chips)	pH Before Contact with the Chips	pH After Contact with the Chips	ΔpH	BOD_5 Before Contact with the Chips (ppm)	BOD_5 After Contact with the Chips (ppm)	Changes in BOD_5 (ppm)
30	0.16	0.1	0.02	10.2	9.1	1.1	330	410	+80
" *	0.16	24	3.9	9.5	8.4	1.1	240	150	-90
" *	0.16	168 (one week)	27.2	9.6	8.1	1.5	190	180	-10
30*	0.16	168 (one week)	27.2	9.9	9.0	0.9	290	290	0
" *	0.16	336	54.4	9.8	8.9	0.9	275	290	+15
" *	0.16	504	71.6	10.2	9.3	0.9	300	320	+20
" *	0.16	1176 (seven weeks)	190.4	9.6	9.2	0.4	210	215	+ 5
" *	0.16	1344 (eight weeks)	217.6	---	---	---	250	210	-40

*The chip pile surface became partially plugged with fibers and the flow of the liquor through the chip pile was thereby considerably reduced.

are stored for relative long periods of time (1 year), does not preserve the wood against degradation. Spraying of chips for a short time, i.e., one month or less, could, according to the literature source (3), offer an economic means of wood protection. Our data show, however, that spraying of stored chips with an alkaline liquor may be a substantial source of water pollution, because organic materials with a BOD_5 of about 5-10 lbs. per ton of dry chips could be extracted from pine chips. Even water extracted a considerable amount of biological oxygen-demanding material from chips. This means that liquor drainage from a chip storage area should be considered as a pollutional waste, and preferably should be treated in the mill's waste treatment plant. The pH changes and color reduction of alkaline waste liquor by filtering it through pine chips are too small to have any practical application in treatment of waste water.

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APPENDIX

Page

Table 1. Properties of waste Kraft pulping liquor before and after gravity flow of the liquor through a column of pine chips (pilot-scale experiments). 35

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Appendix Table 1. Properties of waste Kraft pulping liquor before and after gravity flow of the liquor through a column of pine chips (pilot-scale experiments)

Temp. (°C)	Flow Rate (Gal/lb. Dry Chips/Hr)	Elapsed Time of Liquor Flow (min.)	Total Amount of Liquor Filtered Through the Chips (Gal/Lb Dry Chips)	pH Before Contact	pH After Contact	ΔpH	BOD_5 Before Contact (ppm)	BOD_5 After Contact (ppm)	ΔBOD_5 (ppm)
12	0.7	1	----	9.9	9.0	0.9	380	670	+290
12	0.7	15	0.18	9.8	9.2	0.6	350	600	+250
12	0.7	30	0.35	0.9	9.3	0.5	320	520	+200
12	0.7	45	0.53	9.9	9.5	0.4	310	480	+170
12	0.7	60	0.71	10.0	9.5	0.5	460	330	+130
12	0.7	75	0.89	10.0	0.3	0.7	340	520	+180
13	0.7	95	1.12	9.9	9.5	0.4	350	460	+110
13	0.7	105	1.23	9.9	9.4	0.5	350	440	+ 90
13	0.7	120	1.41	9.8	9.5	0.3	350	430	+ 80
13	0.7	135	1.59	9.9	9.5	0.4	370	470	+100
13	0.7	150	1.77	9.9	9.4	0.5	420	440	+ 20
13	0.7	165	1.94	10.0	9.5	0.5	410	430	+ 20
14	0.7	185	2.18	10.0	9.7	0.3	450	580	+130
14	0.7	195	2.30	10.0	9.7	0.3	450	492	+ 40
15	0.7	210	2.47	----	---	---	530	510	- 20
15	0.7	225	2.65	----	---	---	510	600	+ 90
15	0.7	240	2.82	----	---	---	620	680	+ 60
15	0.7	255	3.00	10.3	10.0	0.3	560	540	- 20
14	0.7	275	3.24	----	---	---	520	530	+ 10
13	0.7	285	3.35	----	---	---	490	560	+ 70
13	0.7	300	3.53	----	---	---	490	500	+ 10
13	0.7	315	3.70	----	---	---	450	480	+ 30
13	0.7	330	3.88	----	---	---	450	470	+ 20
12	0.7	345	4.06	10.0	9.8	---	440	450	+ 10

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Appendix Table 1 (continued)

Temp. (°C)	Flow Rate (Gal/lb. Dry Chips/Hr)	Elapsed Time of Liquor Flow (min.)	Total Amount of Liquor Filtered Through the Chips (Gal/Lb Dry Chips)	pH Before Contact	pH After Contact	ΔpH	BOD_5 Before Contact (ppm)	BOD_5 After Contact (ppm)	ΔBOD_5 (ppm)
10	0.7	1	----	10.5	9.5	1.0	330	660	+340
10	0.7	15	0.18	10.5	9.7	0.8	560	680	+120
10	0.7	30	0.35	10.4	9.8	0.6	380	550	+170
10	0.7	45	0.53	10.5	9.9	0.6	410	580	+170
10	0.7	75	0.89	10.5	10.2	0.3	420	520	+100
10	0.7	90	1.06	10.5	10.2	0.3	400	400	+ 60
11	0.7	105	1.23	10.4	10.1	0.3	400	470	+ 70
11	0.7	120	1.41	10.4	10.1	0.3	430	470	+ 40
11	0.7	135	1.59	10.3	10.0	0.3	440	450	+ 10
11	0.7	150	1.77	----	----	---	470	430	- 40
120	0.7	165	1.94	10.4	10.2	0.2	460	480	+ 20
12	0.7	180	2.12	----	----	---	410	460	+ 50
13	0.7	195	2.30	10.4	10.2	0.2	480	510	+ 30
13	0.7	210	2.47	----	----	---	430	500	+ 70
14	0.7	225	2.65	10.4	10.2	0.2	550	460	- 90
14	0.7	240	2.82	----	----	---	490	490	0
14	0.7	255	3.00	10.4	10.2	0.2	580	600	+ 20
15	0.7	270	3.18	----	----	---	550	540	- 10
15	0.7	285	3.35	10.4	10.2	0.2	560	620	+ 60
15	0.7	300	3.53	----	----	---	600	630	+ 30
15	0.7	330	3.88	10.4	10.2	0.2	590	610	+ 20
15	0.7	360	4.23	----	----	---	420	470	+ 50
13	0.7	375	4.41	10.4	10.2	0.2	430	500	+ 70
13	0.7	390	4.49	----	----	---	450	490	+ 40
13	0.7	405	4.77	----	----	---	420	490	+ 70
13	0.7	420	4.95	----	----	---	400	470	+ 70
13	0.7	438	5.13	----	----	---	440	490	+ 50
13	0.7	450	5.30	10.4	10.2	0.2	420	480	+ 60